# Effects of Post-Fire Logging on Plant Communities in Western Montana

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## Summary

Monitoring plots were established in six study areas in western Montana and northern Idaho to evaluate the initial effects of post-fire logging on mid to high elevation forested ecosystems. Our sites included Douglas-fir, and subalpine fir habitat types. In all cases natural forest regeneration was successful within two years following logging, although tree densities varied according to harvest and yarding technique. There was some evidence of an initial decline in plant species richness following logging. We expect logged sites will fully recover their plant diversity within 5-10 years based on results of other studies in the region. Ten years following logging we were still able to detect the influence of logging on vegetation lifeform development, primarily where tractor yarding was used. Relatively few species were associated with any single treatment. Vegetation lifeforms were more closely associated with logging effects, especially on the most heavily disturbed sites. Grasses most often dominated sites with heavy soils disturbance. Shrubs declined in cover even 10 years after treatment. We found little evidence of noxious or even exotic species invading logged sites, except in the case of Canada thistle in tractor-logged areas. Community analysis of vegetation in the western Montana and Idaho sites suggests that dry sites on south or southwest exposures may be more sensitive to logging related disturbances than more mesic sites. A more extensive monitoring network is needed to verify which types of sites are most sensitive to this form of disturbance in our region. The sensitivity of vegetation to site effects will require extensive replication of study plots to determine general patterns in this region.

## I. Introduction

In recent years, considerable debate has occurred on the ecological impacts of post-fire salvage logging (Lindenmeyer et al. 2004; Lindenmeyer and Noss 2006, Beschta et al. 2004; Donato et al. 2006). While salvaging burned timber after wildfire is a common, and long-standing practice, relatively few data are available to evaluate its ecological effects. It is important that land managers understand potential effects of post-fire salvage logging to make informed decisions on when it is appropriate to use salvage logging to achieve management goals, and once a decision has been made to salvage log an area how to best minimize resource impacts from this kind of logging. We initiated this study to provide both a methodology for assessing the ecological impacts of these kinds of forestry practices and to help provide managers with guidance on the tradeoffs involved in varying logging intensity and technique within a given project area.

Fire is the most common and widespread naturally occurring agent of disturbance in the northern Rocky Mountains and explains many of the key adaptive features of trees and vegetation in our region (Agee 1993; Habeck and Mutch 1973). Wildland fire typically creates a complex mosaic of patches of standing-dead, downed trees and living vegetation. These patches provide important sources and sites for plant recruitment, unique habitats for birds and insects, and refuges for amphibians and small mammals (Forsman 2006; Hutto 1995, 2006, Smucker et al. 2005). Fire also has a profound influence on nutrient availability which largely explains the changes in plant growth rates, morphology, reproduction and competitive relationships which occur after fire (e.g. Agee 1993, Neary et al. 1999).

Post-fire salvage logging is a common practice on many private and public lands for the purposes of a providing a local economic stimulus, improving forest health, and reducing future fire hazard (e.g. Gorte 1996). Little is known about the effect of fire and subsequent salvage logging on plant communities, particularly the understory community. Ecologists have known for some time that multiple perturbations may significantly alter ecosystem structure and function from what it would be following only one perturbation (Paine et al 1998). The effects of post-fire salvage logging, occurring during the same growing season or up to several seasons later, is quite distinctive from the effect of fire itself (Lindenmeyer and Noss 2006, Kotliar et al. 2002). Most studies, both in the US and abroad have found that salvage logging sets back plant succession and ecosystem recovery (Beschta et al. 2004, Donato et al. 2006, Greenberg et al. 1995, Hanson and Stuart 2005, Lindenmayer et al. 2004, McIver and Starr 2000, Purdon et al. 2004, Spanos et al. 2005). It is unclear how this effect may vary by forest type, fire intensity, and logging prescription. Purdon et al. (2004) for example found overstory

stand composition and fire severity to be strong determinants in the species occurring during early succession after fire in boreal forests. In their comparisons with salvage-logged areas, they found that salvage logging tended to homogenize understory composition similar to a high intensity fire. Kurulok (2004) found understory species richness and diversity greater in post-burn, salvage-logged boreal sites, however most of this increase was due to invasive species. In a recent study in the Bitterroot Mountains of western Montana, Hollingsorth (2005) found no significant difference in species richness of vegetation in a comparison of post-fire unlogged and logged sites, however there was a difference in evenness, or relative abundance of species. The vegetation cover in logged areas was dominated by a few species while the vegetation cover in unlogged areas was more evenly split among all species. It is well known that understory plant diversity declines immediately after logging (Halpern and Spies 1995). However this decline in diversity usually persists only one to two years after logging (Halpern and Spies 1995, Stickney 1985).

It is unclear how logging generally influences ecosystem recovery and post-fire succession since there are so many confounding factors including the nature of the fire itself, climatic and soils influences, and the many ways in which forests can be logged. Disturbance influences the heterogeneity of the vegetation at any scale, from stand to landscape. The remaining vegetation, living and dead, after a natural disturbance, is an important part of the biological legacy – strongly influencing the post-disturbance plant and animal communities (Lindenmayer and Franklin 2002). In the case of wildland fire, the severity of the fire varies greatly across the burned area and affects the number, type, and spatial pattern of the biological legacies. Many plant species reproduce most effectively following fire (Agee 1993, Fire Effects Information System database at www.fs.fed.us/database/**feis**/). These factors together explain why fire generally promotes plant biodiversity, especially at the landscape scale in the northern Rockies.

Anecdotal evidence and ongoing studies in our region suggest that weeds are likely to increase in abundance following fire or logging. Disturbance creates a unique environment in terms of nutrient availability, seedbeds, and microclimate which tends to favor exotic invasive species (Mack et al. 2000). Historically, native species dominated the early successional niche of disturbed sites but in recent years with the introduction of highly competitive non-native species such as spotted knapweed, dalmation toadflax, yellow star thistle and cheatgrass, exotic species can play a key role in early post-fire succession. It is not clear how salvage logging may alter the role of exotic species in post-fire environments.

One of the major problems in comparing the various study results and in drawing clear conclusions, is the wide variance in site characteristics, pre-fire disturbance history, fire characteristics, and harvest prescriptions, all of which influence the post-fire and post-logging environment. As summarized by McIver and Starr (2000) proponents of salvage logging claim ecological effects of salvage logging can include reduction of pests, reduction of fuel loading, and better conditions for plant regeneration; those opposing salvage logging claim salvage logging can increase erosion, compacts soils, removes organic materials, and that it has a negative effect on vegetation recovery. Data to support

all positive and negative claims are still inconclusive, particularly across different fires and ecological settings. Until more detailed studies with repeated measurements have been conducted over a long period of time, the most critical need is to establish a monitoring network across a wide geographic area with a range of logging techniques to see if there are emergent trends in the initial vegetative response to post-fire logging.

This study evaluates the effects of salvage logging on vegetation in five study areas scattered across the northern Rockies from near Yellowstone to the Idaho Panhandle, with a range of logging intensities and techniques to provide a preliminary look at ecological effects of salvage logging in this region. We were specifically interested in determining if post-fire salvage logging is associated with changes in tree regeneration, plant diversity, exotic weed invasions, and understory cover.

## II. Study Goals and Objectives

The goals and objectives for this project focused around the following five questions.

1. **Is there a significant difference in vegetation composition and diversity between logged and unlogged sites?**
2. **Which plant species are most highly correlated with salvage logging treatments?**
3. **Is there a significant difference in vegetation structure between logged and unlogged sites?**
4. **Is there a significant difference in tree regeneration between logged and unlogged sites?**
5. **Is vegetation response significantly correlated to harvest technique?**

## III. Methods

### Study Design

In this study we were able to utilize two main datasets. First we established a new set of plots within 4 study areas following wildfires which burned during the summer of 2003. These plots allowed us to examine the initial effects of salvage logging treatments and provide a monitoring network for measuring the long-term effects of these treatments on plant communities. Secondly we utilized data from an early study on the Gallatin National Forest in which we were able to examine the effects of harvesting techniques on general aspects of plant communities 7-10 years after logging. Since each of these components of our study employed different methodologies we describe them separately below.

### A. 2003 Burns

## Study Area

Three study sites were selected in western Montana and one in northern Idaho (Figure 1). The selection process first of all consisted of finding sites that burned in a wildland fire in 2003 and then subsequently underwent a salvage harvest within the first one to three years following the fire. In addition, an effort was made to find sites that were similar in elevation, habitat type, and logging prescription.

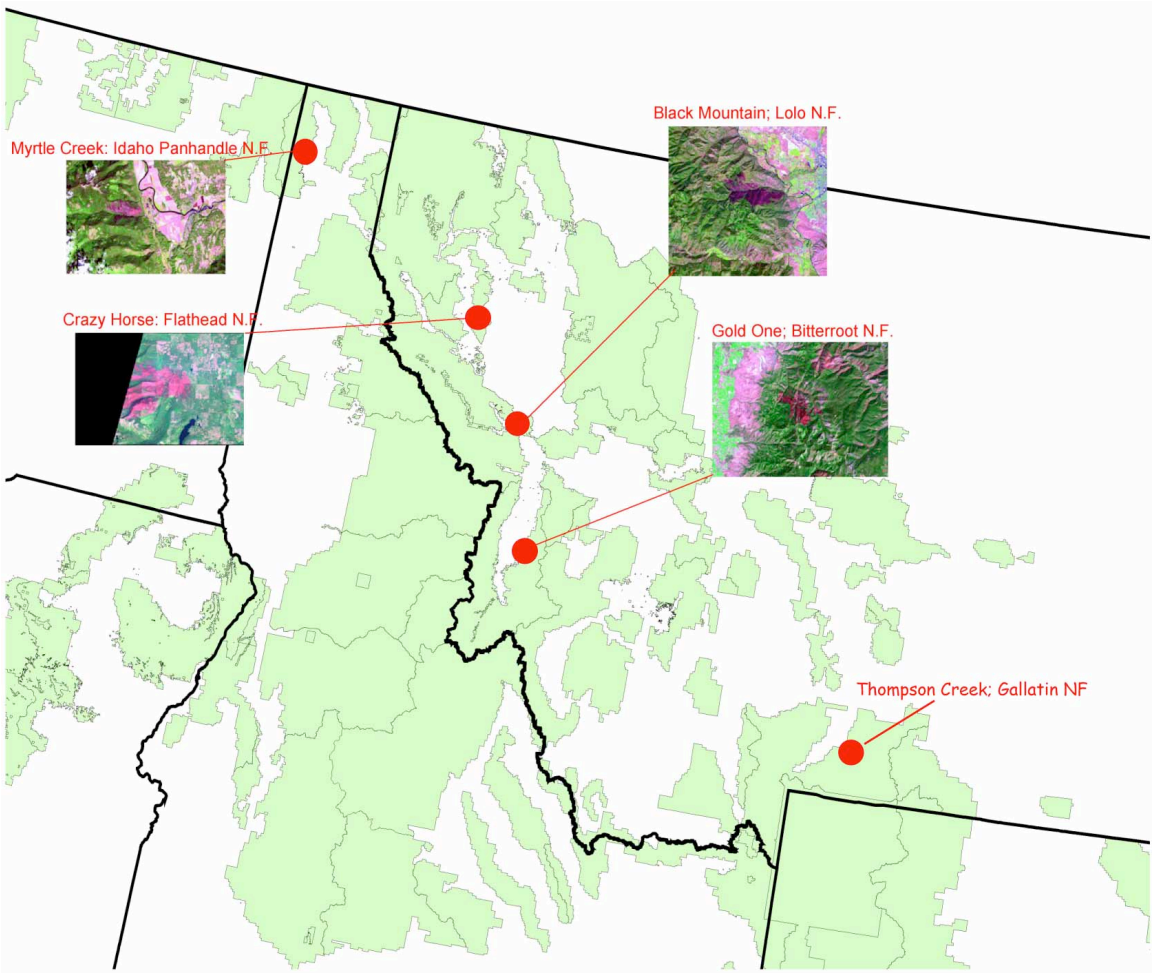
Myrtle Creek: Idaho Panhandle N.F.
Black Mountain; Lolo N.F.
Crazy Horse: Flathead N.F.
Gold One; Bitterroot N.F.
Thompson Creek; Gallatin NF

Figure 1. Study sites for our study. Shaded areas indicate national forests. Solid circles show study area locations. Wildfires associated with each study area are shown in inset figures. Source: USDA Forest Service GIS data.

The Gold One Fire is on the Stevensville Ranger District of the Bitterroot National Forest in western Montana. The Crazy Horse Fire is located on the Flathead National Forest in the vicinity of Lindbergh Lake in the Seeley-Swan area. The Myrtle Creek Fire is in the municipal watershed for Bonner's Ferry, Idaho. For these three sites, we had treatment (post-burn, logged) plots and control (burned, unlogged) plots. The Black Mountain Fire occurred west of Missoula,. This site was treated as a case study because of the lack of an acceptable control area.

Table 1. Burn severity for 2003 burn sites.

| Site | Surface | Low shrub | Med shrub | Overstory |
|---|---|---|---|---|
| Gold One SE | Light | Light | Light | Moderate |
| Gold One NE | Light | Moderate | Mod to High | Mod to High |
| Black Mtn | Moderate | Moderate | NA | High |
| Myrtle Ck | Mod-High | High | High | High |
| Crazy Horse | Light | High | High | High |

**Fires**

All of the wildfires in our study plots resulted in high overstory mortality, but varied in surface and understory burn severity (Table 1). The Gold One Fire burned approximately 8300 acres of land in the Burnt Fork drainage of the Bitterroot National Forest, Montana. A small portion of the fire burned to the west of Gold Creek adjacent to existing roads and was the area where salvage logging was focused; the majority of the fire burned in the Stony Mountain Rare II Inventoried Roadless Area. We established two different sites on the Gold One burn so as to document the effect of aspect on treatment effects. We refer to these plots as Gold One SE and Gold One NE. The salvage logging environmental assessment of Gold One described the pre-fire condition as a moderately warm and dry area of Douglas-fir with a minor component of lodgepole pine and very minor amounts of scattered ponderosa pine, overstocked, and likely stressed due to overstocking and drought. The harvest prescription was for salvage and regeneration harvest (regeneration by natural or planting) of about 130 acres to remove fire-killed, beetle killed trees and beetle-infested trees (dying trees).

The Crazy Horse Fire affected approximately 30 percent of the 35,800-acre Glacier Creek watershed on the Flathead National Forest, Montana (USDA 2004). Estimates derived from aerial detection mapping, with ground verification, show 60 percent of the forest was burned in a stand replacing (high severity) fire, 30 percent mixed severity fire, and 8 percent low severity fire (USDA 2004). The remainder was unburned.

The Myrtle Creek Fire site is located on the Idaho Panhandle National Forests, Bonners Ferry Ranger District. Myrtle Creek watershed is the municipal watershed for Bonners Ferry, Idaho, and is located northwest of Bonners Ferry on the east slope of the Selkirk Mountains. The Myrtle Creek Fire began in a landing pile on the Mama Cascade Timber Sale in September of 2003. The soil burn severity was relatively equal with 31% of the area rated as high, 34% rated as moderate, and 35% rated as low (USDA 2006). The Mama Cascade Timber Sale occurred from 2002 to 2004 in the area where our study sites were placed. Logging had occurred prior to the fire however standing live timber still occurred prior to the fire.

The Black Mountain Fire burned 7,061 acres in August and September 2003, southwest of the Missoula, Montana. Our study site was placed on private land, surrounded by the

Lolo National Forest. The site had historical logging as evidenced by stumps blackened by the fire. There is no documented prescription for this harvest. However, it appears the direction was to clearcut, removing most dead and live trees.

Table 2. Site characteristics for 2003 burn study plots (T= treatment (logged); C=control (unlogged)).

| Site | Habitat Type* | Potential Vegetation Series* | Elevation (feet) | Average Slope | Average Aspect (degrees) | Mean Annual Temperature (°C) |
|---|---|---|---|---|---|---|
| **Gold One SE** | Subalpine fir/twinflower (ABLA/LIBO) | Subalpine fir (ABLA) | 6200 | T 31% C 34% | T 162 C 165 | --** |
| **Gold One NE** | Subalpine fir/twinflower (ABLA/LIBO) | Subalpine fir (ABLA) | 6200 | T 18% C 19% | T 72 C 77 | 3.97 |
| **Crazy Horse** | Subalpine fir/twinflower (ABLA/LIBO) | Subalpine fir (ABLA) | 6165 | T 43% C 39% | T 96 C106 | 4.35 |
| **Myrtle Creek** | Douglas-fir/common snowberry (PSME/SYAL) | Douglas-fire (PSME) | 2950 | T 21% C 37% | T 174 C 159 | 6.14 |
| **Black Mountain** | Douglas-fir/pinegrass (PSME/CARU) | Douglas-fire (PSME) | 4950 | T 47% | T 151 | -- |

*From Pfister et al. 1977

**Data not available

## Environment

Our study areas represent a range of environments from mid- to upper-elevation. Two of our sites were in moist subalpine fir habitat types averaging 6200' elevation, and two represented mid-elevation Douglas-fir series from 3-5,000 feet in elevation (Table 2). Most of the sites were also on a warm dry south to southeastern exposure except for Gold I NE on a cool northeastern exposure. Our air temperature data confirmed the general pattern of elevation, aspect, and vegetation of our plots with the warmest temperatures on Myrtle Creek and the coolest at Gold I. Nearby weather stations and correction for topography suggest that Black Mountain should have been fairly warm with temperatures intermediate between the Myrtle Creek site and the Crazy Horse site.

## Plot Design

Plot layout was similar to the plots being used by the Intermountain Research Station, Moscow, Idaho and the national FIA (Forest Inventory and Analysis) sample design (Ferguson 2001). Four circular subplots were laid out with equal distance (120') between plot centers (Figure 2). Habitat type and overstory burn severity was sampled on 1/24-acre circular plots (Table 1). Overstory trees were sampled using a variable radius plot as sampled by Ferguson (2001). Basal area factors of 10, 20, or 40 square feet per acre were used.

The smallest subplots, 1/300-acre (13.5 $m^2$), were used to estimate understory cover and tree regeneration. Percent cover estimations were made of all understory species, to the nearest 1%, and estimations of understory height class were made to the nearest 10cm. For plants that were difficult to identify in the field, reference specimens were collected, dried and mounted and keyed out in the lab. Standard USDA-NRCS codes were used for these species (USDA, NRCS 2004, http://plants.usda.gov/). The 1/300-acre plot, 1/24-acre plot, and variable radius plot all had the same plot center. A reference point outside of the plot area (and outside of cutting units) provided a long-term marker for future plot location. This was marked and described with regard to its relation to the first circular plot.

If space in salvage units did not allow for this plot design, then the following process was used. The distance of available sampling space was measured. Available sample space was defined as the area within a harvest unit suitable for sample plots (away from the influence of roads and edges and reasonably homogeneous with regard to fire boundaries, topography, soils, etc.). The four plots were spaced across the available sample space as much as possible with a maximum distance of 120' between plots (Figure 3). Plots were an equal distance apart. Plot layout occurred in a line along the optimal length, generally occurring parallel to the slope.

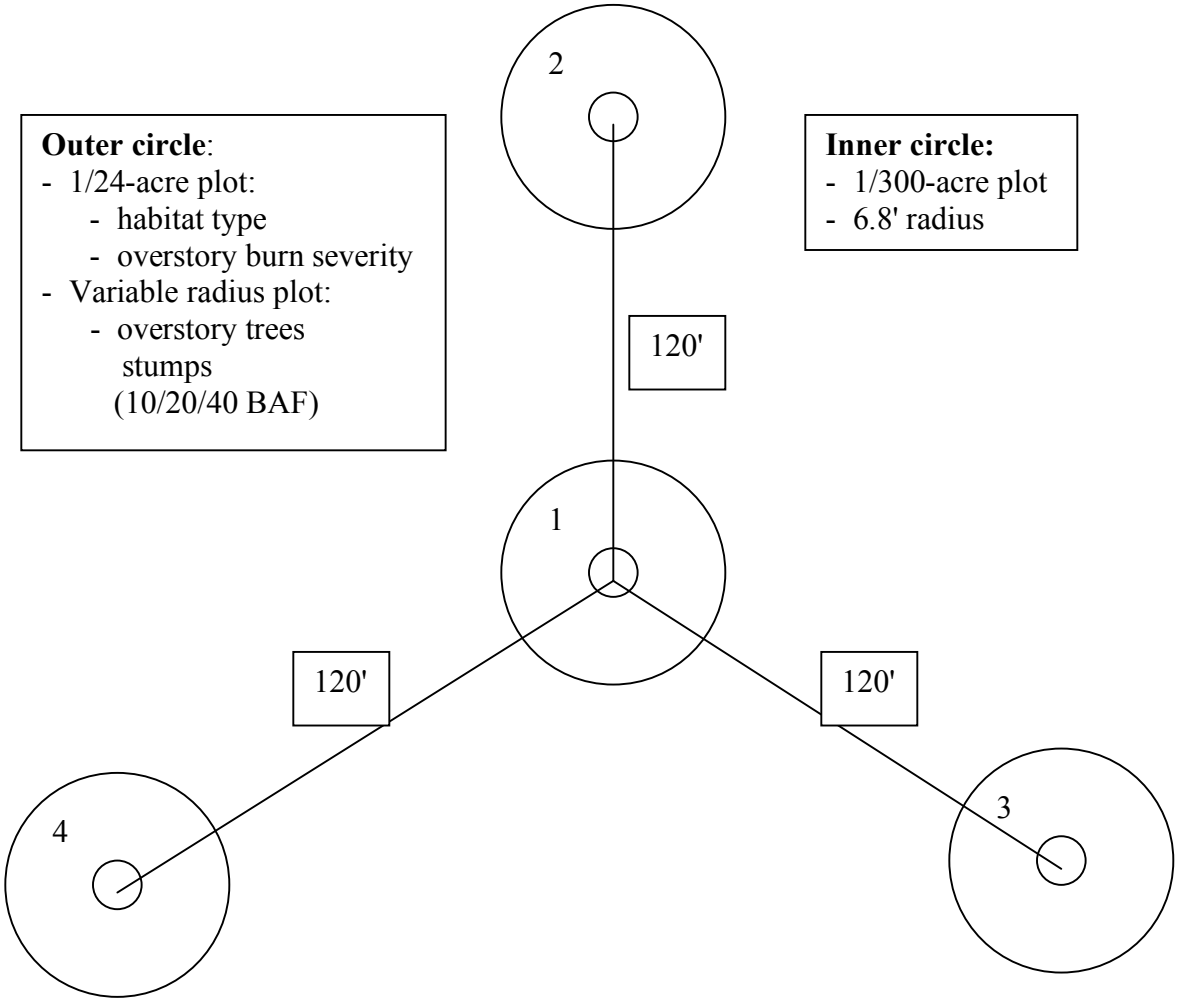


Figure 2. Schematic of standard plot layout from Ferguson (2001)

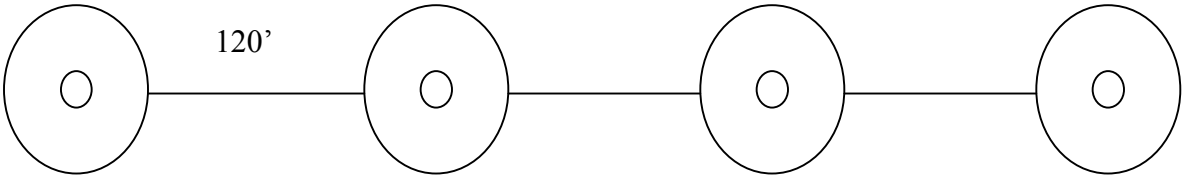


Figure 3. Schematic of modified plot layout adapted from Ferguson (2001) for salvage logged areas in which there was not enough sample area to establish the triangular subplot configuration.

A stump inventory was conducted using a variable plot sampling protocol on each of the subplots. BAF factors of 10, 20 or 40, were used to obtain a sufficient average number of trees per plot, depending on the site. Cut stump diameter, height, and species was measured in the field. The diameter at breast height (dbh) was estimated from cut diameter using methods described by Avery and Burkhart (1983), where stump diameters were measured and conversions to dbh were made through regression equations. Regression equations for predicting dbh from stump diameter do not exist for all species. The Forest Service has a program for predicting dbh from stump diameter for use in timber theft investigations, however we were unable to use the program because of our variable plot sampling method rather than fixed plot. We used existing regression equations for the most similar sized species available. For Douglas-fir, regression equations developed for Black Hills ponderosa pine were used (Avery and Burkhart 1983). Lodgepole pine were estimated from regression equations developed for loblolly pine (Bylin 1982).

Table 3. Variables measured and recorded for each plot and subplot.

**Variable**

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Stand (plot level)

- Unique identification number
- Elevation
- Topographic position

SubPlot

- ID (1-4)
- Burn severity
- Slope and aspect
- Habitat type
- Down woody debris

Shrubs, forbs, grasses, and ferns (1/300 acre)

- % cover for each shrub and forb species
- Shrub regen mode (sprout, seed)
- Height for each shrub species
- % cover by lifeform
- % cover of tree seedlings
- Other lifeforms (moss, lichen, fungus, etc.)
- % cover non-living material (duff, rock, exposed soil etc.)

Tree regeneration (1/300 acre)

- Talley of existing and new trees
- Remeasurement (height, survival, etc.)

Trees ≥3.0 in dbh

- Trees 3.0 to 4.9 in dbh on 1/300-acre plot
- Trees ≥5.0 in variable radius plot
- Unburned tree stumps tallied in variable radius plot only in post-fire harvest units

**Data Collection**

Vegetation data represented in this report were collected from 2004 to 2006. Data collection began in June and continued through late summer. Field data sheets were hand recorded and then entered into Microsoft Excel spreadsheet then organized into Access databases.

Weather stations were established in representative areas of the control plots at each of the study sites to document climatic differences between study areas. Hobo pro external temperature loggers were used which record air temperature in the logger and soil

temperature on an external probe with an accuracy of 0.2° C (Onset Datalogger Company). The logger was mounted inside a standard Hobo louvered radiation shield so that effects of direct sunlight were minimized, and the soil probe was buried 10cm below the litter surface. The logger was mounted on the north side of a snag near the center of the plot. Loggers were cross calibrated in the lab before deployment and were programmed to collect temperature data every 10 minutes and record hourly averages. These were left in place for one year and then downloaded to laptop computers. Two of the loggers were damaged by small mammals (they severed the cord of the soil temperature sensor). The Black Mountain logger did not work properly, so data is not available for this site.

Soil samples were collected at each site to document texture and chemistry but have not yet been analyzed.

## B. 1991 Burn

### Study Area

The Thompson Creek Fire burned in 1991, south of Livingston, Montana (Figure 1). This site was selected by the Gallatin National Forest for an administrative study on the effects of post-fire salvage harvest. We utilized the data from this study as part of our study, courtesy of the Gallatin National Forest. The Thompson Creek Fire burned approximately 7,700 acres during July and August of 1991in the Mill Creek watershed on the Livingston Ranger District (USDA 1992). Over 4,000 acres burned with a moderate to high burn intensity. Logging occurred beginning in the winter of 1992/1993 and continued through 1997 Ping and DeGeest 2003).

Table 4. Characteristics of Thompson Creek Fire study sites.

| **Site** | **Habitat Type** | **Series** | **Elevation (ft)** | **Average Slope (%)** | Average Aspect (degrees) |
|---|---|---|---|---|---|
| Control 1 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7000 | 33 | **358** |
| Control 2 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7000 | 43 | **308** |
| Control 3 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7600 | 38 | **15** |
| Control 4 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7400 | 35 | **335** |
| Control 5 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7100 | 54 | **40** |
| Control 6 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7400 | 50 | **60** |
| Control 7 | Douglas-fir/ninebark | Douglas-fir (PSME) | 6200 | 69 | **290** |
| Control 8 | Subalpine fir/twinflower and Douglas-fir/ninebark | Subalpine fir (ABLA) (dominant) | 6400 | 53 | **28** |
| Control 9 | Douglas-fir/ninebark/pinegrass | Douglas-fir (PSME) | 6500 | 56 | **130** |
| Control 10 | Douglas-fir/ninebark | Douglas-fir (PSME) | 7500 | 38 | **138** |
| Control 11 | Douglas-fir/ninebark/pinegrass and Douglas-fir/snowberry/pinegrass | Douglas-fir (PSME) | 7200 | 30 | **173** |
| Control 12 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 7000 | 33 | **75** |
| Logged Cable 1 | Douglas-fir/ninebark | Douglas-fir (PSME) | 7000 | 51 | **285** |
| Logged Cable 2 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7600 | 45 | **15** |
| Logged Cable 3 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 6400 | 59 | **313** |
| Logged Cable 4 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7200 | 48 | **70** |
| Logged Cable 5 | Subalpine fir/twinflower and Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7200 | 43 | **303** |
| Logged Cable 6 | Douglas-fir/ninebark/pinegrass and Douglas-fir/snowberry/pinegrass | Douglas-fir (PSME) | 7200 | 41 | **68** |
| Logged Helicopter 1 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7600 | 56 | **24** |

| **Site** | **Habitat Type** | **Series** | **Elevation (ft)** | **Average Slope (%)** | Average Aspect (degrees) |
|---|---|---|---|---|---|
| Logged Helicopter 2 | Subalpine fir/blue huckleberry /Subalpine fir/sweet scented bedstraw | Subalpine fir (ABLA) | 7400 | 49 | |
| Logged Helicopter 3 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7400 | 54 | |
| Logged Helicpter 4 | Douglas-fir/elk sedge | Douglas-fir (PSME) | 7200 | 39 | |
| Logged Helicopter 5 | Douglas-fir/ninebark/pinegrass | Douglas-fir (PSME) | 7100 | 49 | |
| Logged Helicopter 6 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7600 | 38 | |
| Logged Tractor 1 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7600 | 29 | **305** |
| Logged Tractor 2 | Douglas-fir/pinegrass. Douglas-fir/elk sedge, and Douglas-fir/snowberry/pinegrass | Douglas-fir (PSME) | 7000 | 31 | **238** |
| Logged Tractor 3 | Subalpine fir/twinflower and Douglas-fir/ninebark/pinegrass | Subalpine fir (ABLA) | 6400 | 20 | **358** |
| Logged Tractor 4 | Douglas-fir/snowberry/pinegrass | Douglas-fir (PSME) | 6400 | 19 | **320** |
| Logged Tractor 5 | Subalpine fir/twinflower | Subalpine fir (ABLA) | 6600 | 19 | **330** |
| Logged Tractor 6 | Subalpine fir/blue huckleberry | Subalpine fir (ABLA) | 7600 | 15 | **3** |
| Unburned 1 | | | | | |
| Unburned 2 | | | | | |
| Unburned 3 | | | | | |
| Unburned 4 | | | | | |
| Unburned 5 | | | | | |
| Unburned 6 | | | | | |
| | | | | | |

**Study Design**

The study design for this part of the study was designed by scientists from the Rocky Mountain Research Station, Forestry Sciences Laboratory in Moscow, Idaho, specifically for the Gallatin National Forest as an administrative study. The objectives of the administrative study were to analyze the effects to forest resources from various methods

of post-fire salvage operations, as compared to adjacent unharvested, burned and unburned, sites. Data were collected in 2002, seven to ten years after logging.

Thirty-six study areas were randomly chosen from a combination of the harvested units and from adjacent unlogged, burned and unburned sites. Sites were generally on cool moist subalpine fir series sites on north east to northwest aspects 6400-7600' in elevation (Table 4). Six replications of each of the harvest methods (helicopter, cable, and tractor) were sampled. Also sampled were six replications of stands that were burned and not harvested with slopes >35% and < 35%. Six adjacent unburned and unharvested stands were also sampled to serve as a comparison with the burned areas.

Plot design was as described for the 2003 burns above in section A. When plots were established for the Thompson Creek Fire study, plots were established with the FIA layout (Figure 2).

## Data Collection

Sites were treated between 1992-1997. The vegetation and tree regeneration data were collected during the summer and fall of 2002 by Gallatin National Forest personnel, and represent the vegetative communities occurring approximately a decade after fire and 7-10 years after logging (Ping and DeGeest 2003). Vegetation data differs from the 2003 burns in that % cover data was collected only for habitat type indicator species (Pfister et al. 1977), for noxious species, and for vegetation lifeforms, not for all species. It was therefore not possible to estimate plant diversity for these plots. Stump data were not collected for these sites either so we cannot directly assess differences in logging treatment intensity between study sites.

Weather data for 1991 were obtained from the weather station closest to the burn area, which was the Livingston Airport.

## C. Data Analysis (both 2003 and 1991 Burns)

The main objective of our study was to determine if post-fire salvage logging has an impact on understory vegetation diversity, composition, and abundance as compared to sites that were not logged. This objective was broken down into several specific questions. The analysis methods are described specifically for each question below.

1. **Is there a significant difference in vegetation composition and diversity between logged and unlogged sites?**

This question is focused on the 2003 burn study areas since the 1991 burn did not have comprehensive species data collected. Vegetation composition was represented by percent cover of each species. Diversity was determined by species richness which was

total number of species per plot and relative abundance of each species as measured by average percent cover. Average percent cover was determined by averaging cover estimates by subplot, plot and treatment. Relative abundance was then determined by dividing average cover for a given species by the total cover for all species in a plot (McCune et al. 2002). Subplot data were also combined to determine species richness per plot. Additionally diversity was analyzed with a Shannon-Wiener Index a combined measure of species richness and evenness.

$$H = \text{sum}\ (Pi\ 1n[Pi])$$

where Pi (relative abundance) = ni/N

ni = average percent cover for species i

N = total sum of percent cover for all species

H (the index number) ranges from 0 to over 7 with the higher the number representing a more diverse community.

Black Mountain did not have a control (unlogged) site, therefore only the logged site was avilable for analysis.

Changes in overall plant composition were assessed by doing a multivariate analysis of our species abundance (cover) data for all of the plots measured in 2005. We performed a DCA (detrended correspondance analysis) on our species and plot data to determine the overall similarity of plant communities between study areas and between treatments within study areas (McCune et al. 2002). In this analysis we considered the distance in ordination space between plots as the best measure of overall differences in plant community structure and the relative position of communities in ordination space the best indication of their overall relationship to one another in terms of floristic (indirect) gradients (McCune et al. 2002).

2. **Which species are most highly correlated to salvage logging treatments?**

   This question is focused on the 2003 burn study areas. We developed tabular summaries of species abundance by treatment for each study area, and calculated standard errors to assess variability in these estimates. We then tested for the statistical significance of these trends by calculating indicator species scores for all species for both logged and unlogged treatments (McCune et al. 2002, Dufrene & Legendre 1997). We used indicator species analysis rather than the more conventional ANOVA or t-test since this approach does not require data to conform to the very restrictive statistical assumptions of normality and homogeneity of variance that is required by these former approaches. Also ISA better integrates the response of these species relative to overall plant community

responses (McCune et al. 2002). This analysis identifies which species have a significant correlation with a given group or treatment. We considered correlations to be significant when $P \leq 0.05$.

3. **Is there a significant difference in vegetation by life form between logged and unlogged sites?**

   Indicator species analysis was also used to determine which lifeforms were significantly related to logging treatments. This was performed on both the 2003 and 1991 burn data. Lifeforms were considered significantly different when $P \leq 0.05$.

4. **Is there a significant difference in tree regeneration between logged and unlogged sites?**

**Tabular summaries were constructed of the density of tree seedlings per plot in both logged and unlogged plots. We compared the average % stocking of seedlings and average tree seedling density per plot to assess differences. Standard errors were calculated to give a general indication of variability in estimates of regeneration.** **IV.**

## IV. Results

### Treatments

In all study plots the majority of snag or live tree basal area was removed with the salvage logging treatment (Table 5). Most plots had 70-90% of basal area removed with logging, with an average tree diameter of 15-18" (except for one of the Myrtle Creek plots with smaller trees). Approximately half the plots had living trees surviving after the fire, the others had complete overstory mortality and high intensity fire. Snag basal area density varied widely between treatments with a range from 5-153 $ft^2$/acre. The treatments therefore appeared to represent typical if not higher intensities of operational salvage logging operations.

### Weather Patterns

During the period of our study there was a strong pattern of increased spring precipitation and warm summer temperatures, as would be expected during the negative phase of El Nino (Figure 4). The burns in 2003 occurred during a hot dry summer following a dry spring. Logging treatments occurred in 2004 following another dry spring and a warm summer. In 2005 when most of our monitoring data was collected we had a more normal moist spring and hot summer. This mild and moist weather may have contributed to the fast establishment and good survival of vegetation following logging treatment.

Table 5. Summary of salvage logging treatment in the 2003 burn plots. Estimates of basal area removal from stump surveys after treatment with correction to DBH from regression models (see text)

| | | *---- Basal Area, sq ft/acre ----* | | | | *Trees removed* | |
|---|---|---|---|---|---|---|---|
| Study Area | Plot | Removed | Live | Snags | % removed | Average DBH," | Maximum DBH," |
| Myrtle Creek | 10 | 45 | 0 | 20 | 69.2% | 13.0 | 17.5 |
| Myrtle Creek | 11 | NA | 0 | 110 | | | |
| Black Mtn. | 5 | 73 | 0 | 5 | 93.6% | 17.6 | 28.6 |
| Gold One | 1 | 43 | 28 | 25 | 44.8% | 17.5 | 25.2 |
| Gold One | 2 | NA | 58 | 153 | | | |
| Gold One | 3 | 123 | 20 | 13 | 78.8% | 14.6 | 23.0 |
| Gold One | 4 | NA | 30 | 130 | | | |
| Crazy Horse | 15 | 105 | 0 | 13 | 89.0% | 15.7 | 27.7 |
| Crazy Horse | 16 | NA | 0 | 70 | | | |
| Study Average | | 78 | 15 | 60 | 75% | 16 | 24 |

*Trees greater than 20" (51 cm).

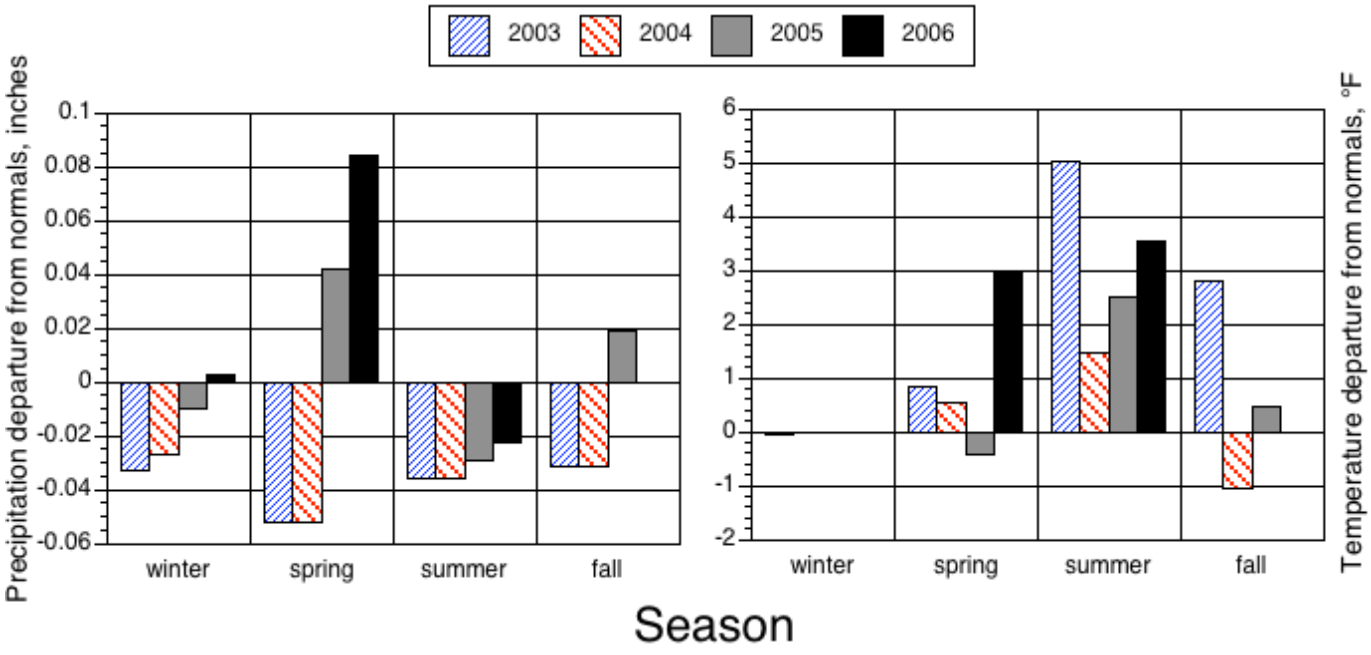


Figure 4. Weather patterns during study. Data represents departures from 30 year normals from Missoula airport.

**Is there a significant difference in vegetation composition and diversity between logged and unlogged sites?**

Noxious weeds

In the analysis of the four 2003 burn sites one of questions relating to vegetation composition was the presence of noxious weeds. Noxious weeds were found on four sites (Table 6). Although present on all sites, the percent cover was relatively low on each site and there was no clear affinity for logged versus unlogged sites. Exotic species were present on all sites (Table 7). The 1991 burn plots had similarly small average cover of noxious species 7-10 years after treatment. Three noxious species were found (spotted knapweed, houndstongue, and Canada thistle). Only Canada thistle had a significant relationship to the logging treatment, which was only for the tractor logging plots.

Table 6. Percent cover of Montana and Idaho state-listed noxious weeds by site for sites burned in 2003.

| *Noxious weed* | *Black Mountain* | *Gold One* | *Crazy Horse – unlogged* | *Myrtle Creek - logged* |
|---|---|---|---|---|
| Spotted knapweed (Centaurea maculosa) | 1.5% | | | |
| Canada thistle (Cirsium arvense) | | 1.5% (logged)<br>1.5% (unlogged) | 1.3% | 1.0% |

Species richness was generally lower on logged sites than unlogged sites in the 2003 burn areas, with the Crazy Horse Fire site having the lowest species richness (Table 8). The Shannon-Weiner index did not show any significant trend with the logging treatment.

One Northern Region (R1) species at risk, *Epilobium palustre*, was found on the Myrtle Creek Fire site on the Idaho Panhandle National Forests. This species was found on all four subplots on the logged sites, with an average of 5.25% cover (range 1 – 10%), and found on three out of four subplots on the unlogged sites, with an average of 5.3% (range 3 – 10%). There was no significant difference in the cover of *Epilobium palustre* between logged and unlogged sites.

Vegetation composition was primarily associated with moisture and disturbance gradients (Figure 5). The major gradient on axis 1 was moisture, with typical species of palouse or mountain prairie dominating the positive end of the axis including balsamroot (*Balsamorhiza sagittata*) and species associated with high elevation acid moist sites on the negative portion of the axis such as black huckleberry (*Vaccinium membranaceum*).

The second axis was mostly associated with a disturbance gradient with exotic invasive grassland species on the negative portion of the axis such as spotted knapweed (*Centaurea stoebe*) and introduced timothy (*Phleum pratense*). On the positive end of the axis native species associated with prairie and

Table 7. Percentage Cover of exotic species on 2003 burns.

| Species | ---------- % Cover ---------- | | | | | | |
|---|---|---|---|---|---|---|---|
| Site Treatment | Black Mtn logged | Crazy unlogged | Crazy logged | Gold unlogged | Gold logged | Myrtle unlogged | Myrtle logged |
| *Agrostis alba* | | | 10.0 | | | | |
| *Asparagus officinalis* | 1.0 | | | | | | |
| *Bromus inermis* | | 1.0 | | | 1.0 | | |
| *Bromus tectorum* | 1.0 | | | | | | |
| *Centaurea maculosa* | 1.0 | | | | | | |
| *Hieracium albiflorum* | | | | | | | |
| *Lactuca serriola* | 2.0 | | | | | 1.0 | |
| *Logfia arvensis* | 0.5 | 1.0 | 1.0 | 1.0 | 0.5 | | |
| *Phleum pratense* | 0.5 | | | | 1.0 | | |
| *Poa compressa* | | | 1.0 | | | | |
| *Poa pratensis* | 0.5 | 1.0 | 1.0 | 1.0 | 1.0 | | |
| *Taraxacum officinale* | 0.5 | 1.0 | 1.0 | 0.5 | 0.5 | | |
| *Tragopogon dubius* | 0.5 | 1.0 | | 1.0 | 0.5 | 1.0 | |
| *Verbascum thapsus* | 1.0 | 2.0 | | 1.0 | 1.0 | | 1.0 |
| Totals | 8.5 | 7.0 | 14.0 | 4.5 | 5.5 | 2.0 | 1.0 |

forests were located including blue-eyed mary (*Collinsia parviflora*), green alder (*Alnus viridis*) and dense spike moss, *Selaginella densa.* Black mountain with its representation of low elevation dry weedy grassland species was the most compositionally distinctive study area. Myrtle Creek represented more of a dry less disturbed site on the opposite side of the disturbance axis. Crazy Creek was mostly distinctive in terms of a moist series of sites. In general the patterns in composition revealed from this analysis suggests that logging had the greatest effect on vegetation in dry sites (Myrtle Creek and Black Mountain) and the least effect on the wettest sites (Crazy Creek). In Gold I where we had a comparison of a wet (north facing aspect) and dry (southwest facing aspect) the same pattern held with minimal change on the wet site and a large change in species composition on the dry site.

Table 8. The effects of logging on plant community diversity for the 2003 burn sites as measured in 2005. SD in parentheses. Significant differences denoted with a *.

| *Site* | *Richness* | | *Shannon-Wiener Index* | |
|---|---|---|---|---|
| | *Logged* | *Unlogged* | *Logged* | *Unlogged* |
| Gold One SE | 25(3)* | 31(5) | 1.16 (0.09) | 1.22 (0.05) |
| Gold One NE | 20(2)* | 25(2) | 1.01 (0.28) | 1.06 (0.08) |
| Black Mountain | 20(3) | | 0.91 (0.05) | |
| Myrtle Creek Logged | 14(4) | 20(5) | 0.63 (0.10) | 0.86 (.16) |
| Crazy Horse Logged | 9(3)* | 14(2) | 0.80 (0.14) | 0.94 (0.15) |

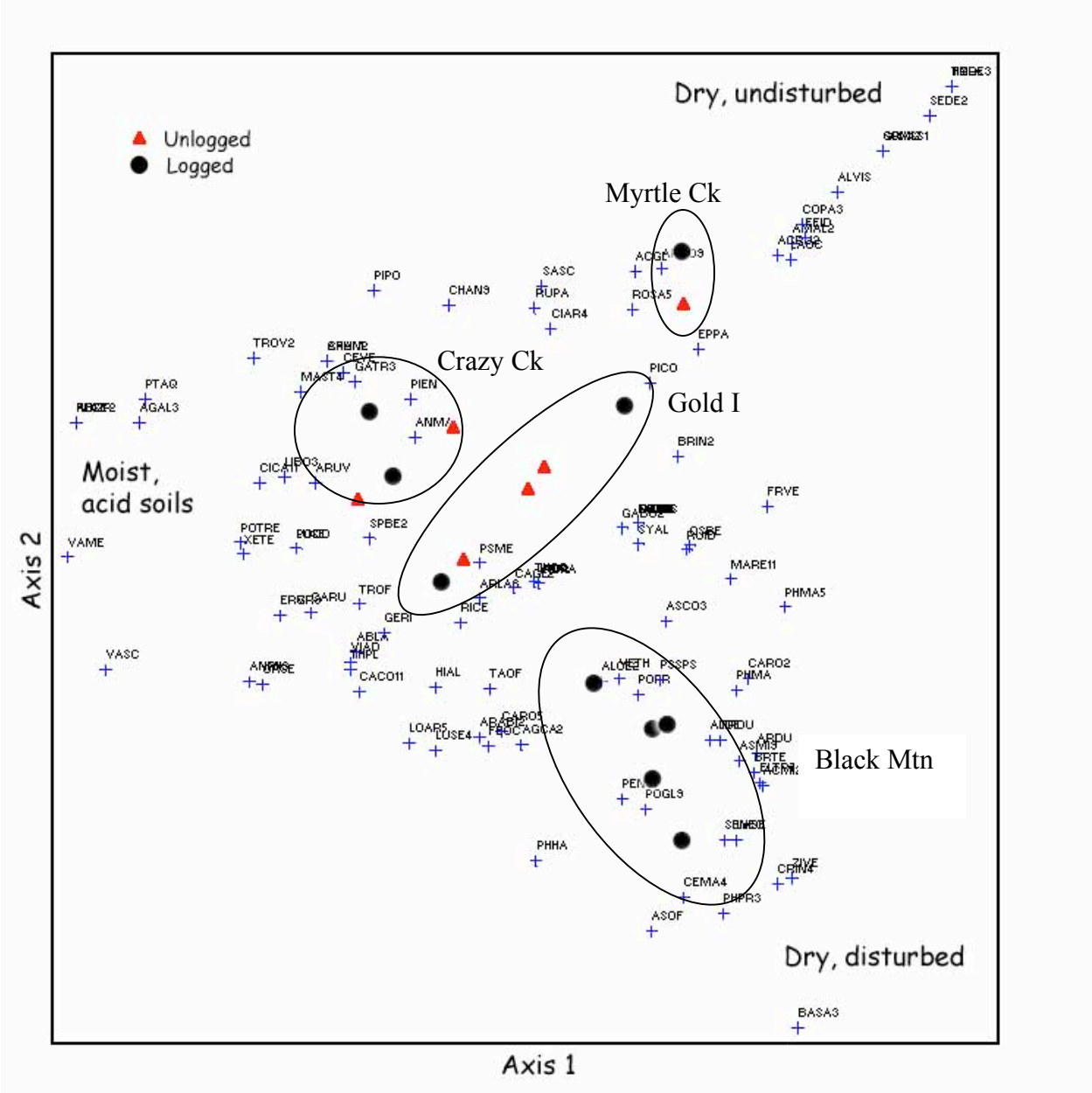


Figure 5. Detrended correspondance analysis of general vegetation patterns in the 2003 burn plots. Each axis is a indirect ordination gradient so represents maximum changes in vegetation composition. Each cross represents the center of distribution of a given species. Species codes follow appendix A1.

Table 9. Indicator species analysis for 2003 burn sites. IV=indicator value or species cover x frequency for a given treatment, Mean=IV for all treatments.

| *Species* | *IV* | *Mean* | *S.Dev* | *p* | *Treatment* |
|---|---|---|---|---|---|
| *Collinsia parviflora* | 64.5 | 32.5 | 11.50 | 0.006 | unlogged |
| *Amalanchier alnifolia* | 63.3 | 29.1 | 11.45 | 0.013 | unlogged |
| *Rosa woodsii** | 71 | 35.6 | 11.72 | 0.017 | unlogged |
| *Acer glabrum* | 50 | 20.9 | 10.23 | 0.043 | unlogged |
| *Penstemon* spp | 76 | 40.9 | 11.08 | 0.014 | logged |
| *Potentilla glandulosa* | 56.9 | 35.0 | 11.03 | 0.044 | logged |

Table 10. Indicator species analysis for Thompson Creek 1991 burn sites 7-10 years after treatment. IV=indicator value or species cover x frequency for a given treatment, Mean=IV for all treatments.

| *Species* | *IV* | *Mean* | *SD* | *p* | *Treatment* |
|---|---|---|---|---|---|
| *Clematis pseudoalpina* | 14.6 | 3.9 | 2.23 | 0.006 | Control |
| *Saxifraga cernuum* | 14.6 | 4.9 | 2.68 | 0.007 | Control |
| *Physocarpus malvaceus* | 18.2 | 8 | 2.65 | 0.007 | Control |
| *Rubus parviflorus* | 23.7 | 10.3 | 3.18 | 0.005 | helicopter |
| *Ribes lacustre* | 18.1 | 7.7 | 2.82 | 0.008 | helicopter |
| *Ribes viscosissimum* | 22 | 11.6 | 2.91 | 0.008 | helicopter |
| *Rosa* spp | 17 | 7 | 2.83 | 0.008 | tractor |
| *Cirsium arvense* | 14.6 | 6.7 | 3.01 | 0.026 | tractor |
| *Juniperus communis* | 22.3 | 5.6 | 2.76 | 0.002 | unburned |
| *Symphoricarpos albus* | 23.4 | 13 | 2.87 | 0.007 | unburned |
| *Mahonia repens* | 21.1 | 13.4 | 3.26 | 0.030 | unburned |

**Which species are most highly correlated to salvage logging treatments?**

The indicator species analysis for the 2003 burn data suggest that in general, rose (*Rosa* spp), Rocky Mountain maple (*Acer glabrum*), serviceberry (*Amelanchier alnifolia*), and blue-eyed mary (*Collinsia parvifolia*) were the most abundant and consistently associated with unlogged sites (Table 9). There were only two species, *Penstemon* spp. and *Potentilla glandulosa* (cinquefoil) that were associated with logged sites. It is interesting to note that no weedy or disturbance dependent species were significantly associated with the logged sites. Given the strong influence of site moisture on vegetation response to logging it is not too surprising that there are few species which consistently are associated with logged sites.

In the Thompson Creek fire near Livingston by contrast there was a stronger response of vegetation to the salvage logging treatment. Of the 30 species or species groups that were monitored, 11 had a significant association with one of the treatments. No species were specifically associated with the cable logging treatment, again suggesting this treatment

had the least effect on vegetation development. Three native shrubs were associated with the helicopter treatment. One noxious weed species, Canada thistle (*Cirsium arvense*) and native Rose species were significantly associated with the tractor treatment. Interestingly rose was an indicator of logging here, but rose was more associated with unlogged treatments in the 2003 burn plots. The association of rose with tractor logging was stronger than it was with the unlogged treatments in the 2003 burns suggesting that in the later case there could be a localized site effect.

Table 10. Summary of vegetation response to harvest treatment in terms of indicator species percent cover, seven to ten years following harvest of the Thompson Creek Fire, Gallatin National Forest. Reps=6.

| | Treatment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Unburned | | Control | | Cable | | Helicopter | | Tractor | |
| **Forbs** | | | | | | | | | | |
| *Centaurea stoebe* | | | 1.0 | - | | | | | | |
| *Cirsium arvense* | | | 1.8 | (0.5) | 1.0 | (0.0) | 2.0 | (1.7) | 1.5 | (0.8) |
| *Clematis occidentalis* | | | | | 4.0 | - | | | | |
| *Clematis pseudoalpina* | | | 2.0 | - | 1.8 | (0.5) | | | | |
| *Cynoglossum officinale* | | | 1.0 | | 1.0 | - | | | | |
| *Rosa spp* | 1.5 | (0.7) | 2.0 | (0.8) | 1.8 | (1.0) | | | 1.9 | (0.6) |
| *Rubus parviflorus* | 3.3 | (1.5) | 5.4 | (6.1) | 5.8 | (7.4) | 3.7 | (4.9) | | |
| *Saxifraga cernua* | | | | | 7.5 | (11.7) | 1.5 | (0.7) | | |
| *Amelanchier alnifolia* | 4.8 | | 13.2 | | 22.8 | | 7.2 | | 3.4 | |
| **Shrubs** | | | | | | | | | | |
| *Acer glabrum* | 2.0 | - | 7.0 | - | | | | | | |
| *Alnus viridis* | 14.0 | (15.6) | 13.2 | (9.6) | | | 5.0 | - | | |
| *Amelanchier alnifolia* | | | | | | | | | 7.0 | - |
| *Ceanothus velutinus* | | | 11.7 | (17.5) | 4.0 | (1.4) | 36.3 | (35.7) | 7.5 | (11.7) |
| *Chimaphila umbellata* | 5.0 | - | 1.0 | (0.0) | | | | | | |
| *Juniperus communis* | 24.7 | (25.0) | | | | | | | 1.0 | (0.0) |
| *Lonicera utahensis* | 8.5 | (3.6) | 3.6 | (1.9) | 2.8 | (2.4) | 4.0 | (4.3) | 1.6 | (0.8) |
| *Mahonia repens* | 3.4 | (2.0) | 3.5 | (3.6) | 2.1 | (1.3) | 2.0 | (1.0) | 2.7 | (2.0) |
| *Physocarpus malvaceus* | 3.0 | - | 27.1 | (19.0) | 14.1 | (11.4) | 15.0 | (0.0) | | |
| *Prunus virginiana* | | | 1.0 | - | | | | | | |
| *Ribes lacustre* | 1.0 | - | 3.6 | (3.0) | 3.0 | (1.7) | 5.3 | (4.2) | 1.0 | (0.0) |
| *Ribes viscosissimum* | | | 2.9 | (1.7) | 6.5 | (5.2) | 7.8 | (7.8) | 1.0 | (0.0) |
| *Salix spp* | | | | | | | 1.0 | (0.0) | 1.5 | (0.7) |
| *Sambucus racemosa* | | | 3.5 | (2.4) | | | 4.0 | (0.0) | | |
| *Shepherdia canadensis* | 3.0 | - | 5.0 | - | 7.0 | (0.0) | 7.7 | (2.1) | 3.0 | - |
| *Spiraea betulifolia* | 5.1 | (5.5) | 7.9 | (6.0) | 6.6 | (5.3) | 6.7 | (4.7) | 3.9 | (2.3) |
| *Symphoricarpos albus* | 11.6 | (7.5) | 10.5 | (7.7) | 2.4 | (1.5) | 6.0 | (7.8) | 6.7 | (6.6) |
| *Vaccinium caespitosum* | | | | | 2.0 | - | 3.0 | - | 2.0 | (0.0) |
| *Vaccinium membranaceum* | 7.3 | (3.3) | 5.8 | (3.6) | 3.0 | (2.3) | 6.4 | (4.9) | 6.4 | (7.0) |
| Average | 7.4 | | 7.1 | | 4.9 | | 7.9 | | 3.5 | |
| Richness* | 14.0 | | 21.0 | | 18.0 | | 17.0 | | 15.0 | |

*Number of species per treatment

**Is there a significant difference in vegetation by life form between logged and unlogged sites?**

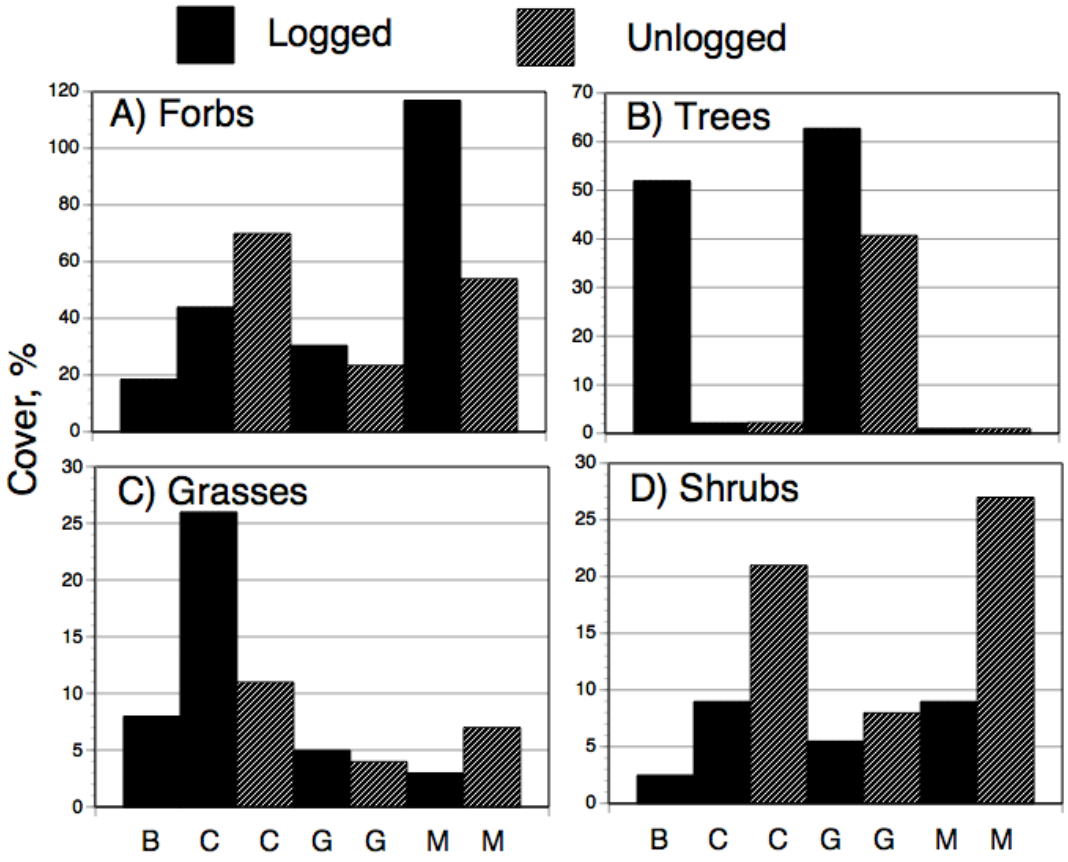


Figure 6. Average percent vegetation cover by lifeform for 2003 burn sites. B=Black Mountain, C=Crazy Horse, G=Gold Creek, M=Myrtle Creek.

On the 2003 burn plots there was not a consistent overall pattern to the effects of logging on most vegetation lifeforms (Fig 6). Black Mountain in general had low vegetation cover compared to the other sites. At Crazy Horse grasses responded strongly to logging treatment. At Myrtle creek forbs responded the most strongly to logging. There was no significant effect on tree seedling cover, except that tree seedlings actually increased after logging at Gold Creek. At all of the sites shrub cover declined with logging treatment, this was especially significant at Myrtle Creek and Crazy Horse.

Table 11. Vegetation lifeforms significantly associated with logging treatments at the Thompson Creek fire. IV is importance value (average cover x frequency) for all treatments, mean=IV for the treatment most associated with this lifeform.

| *Lifeform* | *Treatment* | *IV* | *Mean* | *Stan. Dev* | *p* |
|---|---|---|---|---|---|
| Litter | control | 24.6 | 21.5 | 1.34 | 0.013* |
| Moss | cable | 21.8 | 21.9 | 1.86 | 0.464 |
| Rock | cable | 19 | 11.8 | 3.2 | 0.038* |
| Shrubs | helicopter | 28.1 | 24.1 | 2.15 | 0.040* |
| Slash | helicopter | 32.6 | 20.8 | 2.22 | 0.001* |
| Grass | tractor | 30.2 | 22.6 | 1.75 | 0.001* |
| Exposed Soil | tractor | 29 | 17.6 | 2.92 | 0.002* |
| Forbs | unburned | 25.8 | 23.4 | 1.77 | 0.086 |
| Lichens | unburned | 10.8 | 6.9 | 2.5 | 0.081 |

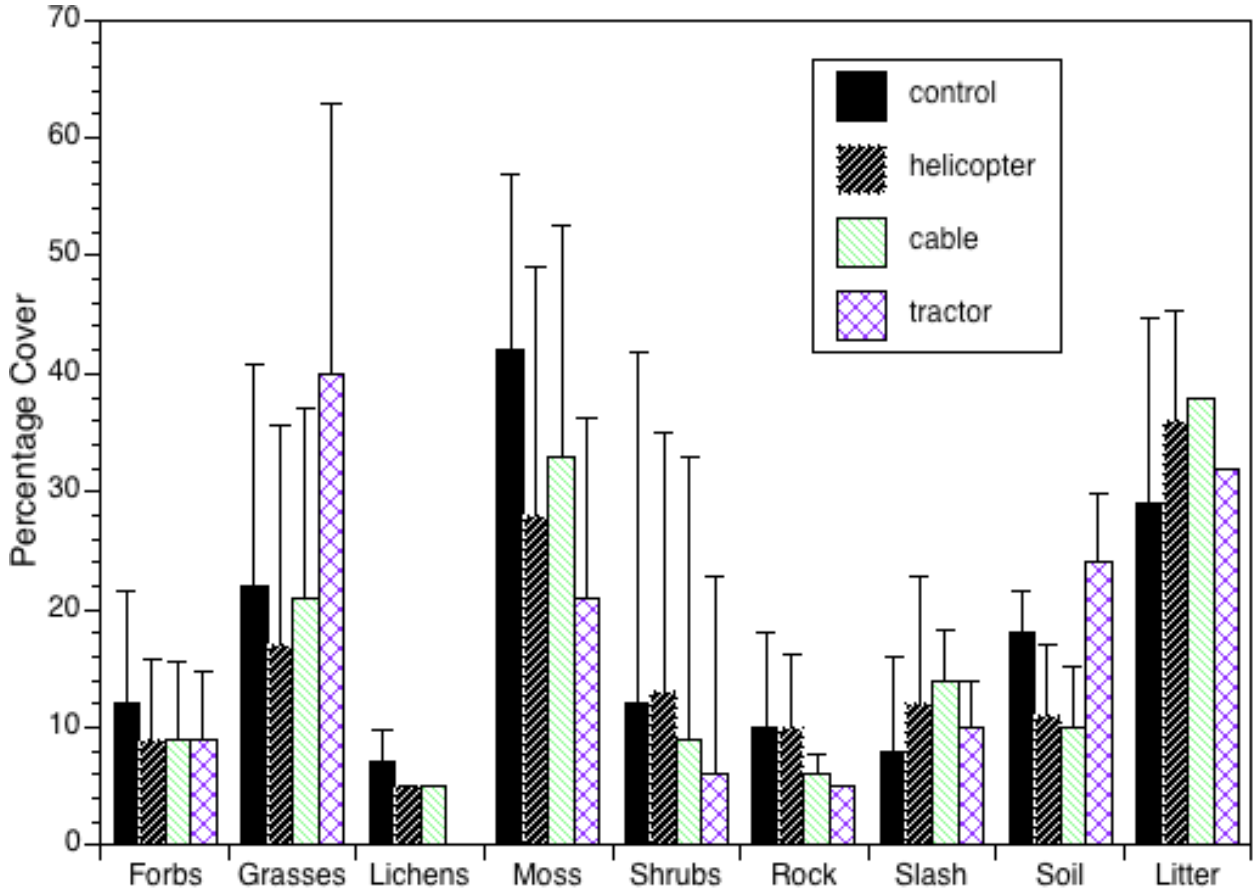


Figure 7. Percent cover of vegetation by lifeform at the Thompson Creek burn plots, 7-10 years after logging. Error bars represent standard errors of average cover.

For the Thompson Creek burn plots a much stronger pattern was detected in response to logging treatment (Table 11, figure 7). The only lifeform that was best expressed on the control (unlogged) plots was litter. Harvest technique had a significant effect on which lifeform was most common after logging. Cable logged plots had more moss and rock cover than other sites. Shrubs and slash were most common in the helicopter logged sites. Grasses and exposed soil were most common on the tractor logged sites. Shrubs were also significantly reduced, even 10 years after treatment following tractor logging. There were not any lifeforms of vegetation that were best expressed on the unburned plots. There was substantial variability between plots, indicating that the response of vegetation was also influenced by site level factors.

**Is there a significant difference in tree regeneration between logged and unlogged sites?**

There was little overall effect of logging on tree seedling density on the 2003 burn plots (Figure 8). Crazy Horse, Myrtle Creek, and the two sites on Gold One all had a minimum of 300 seedlings per acre on both the control (unlogged) and the treated plots. Crazy Horse and Myrtle Creek both had a higher numbers of seedlings on the treatments, while the two Gold One sites had lower numbers of seedlings on the treatments. The Black Mountain site, the most disturbed of our sites burned in 2003, had no regeneration on the plot samples. One dead seedling was observed outside of the plots walking to and from the plot locations.

On the Thompson Creek fire logging and harvest treatment had a significant effect on natural tree regeneration (figure 9). As in the 2003 burn plots all plots had adequate tree regeneration (>300 seedlings/acre) 7-10 years after logging. The species best adapted to these high elevation sites, subalpine fir, regenerated well after logging regardless of harvest technique. In fact there were higher tree seedling densities in logged plots than control plots. All species but Douglas-fir also regenerated better after logging with helicopter yarding than in the control plots. All species except for subalpine fir had significantly less tree regeneration on tractor logged treatments than the control plots.

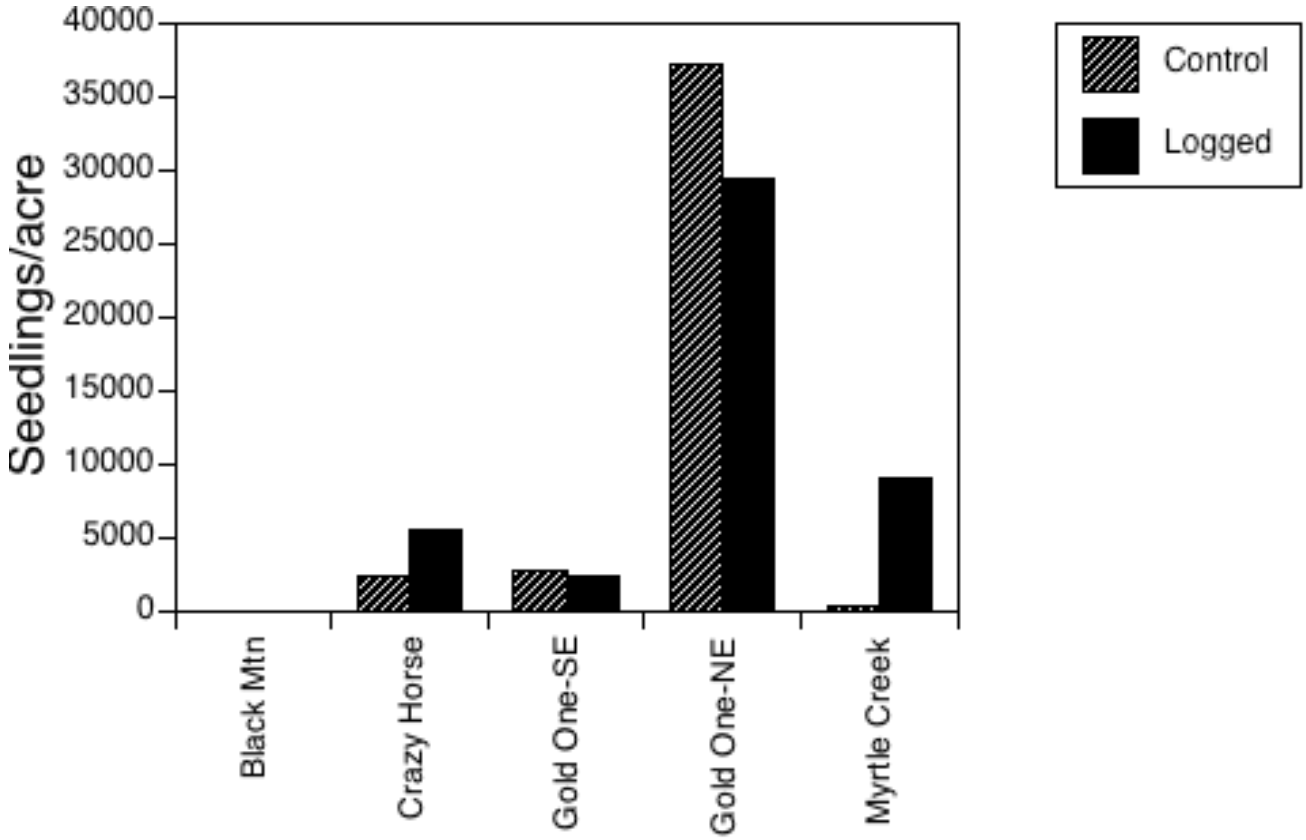


Figure 8. Tree regeneration on the 2003 burn sites, three years after fire. Data represent average densities for each treatment in each site.

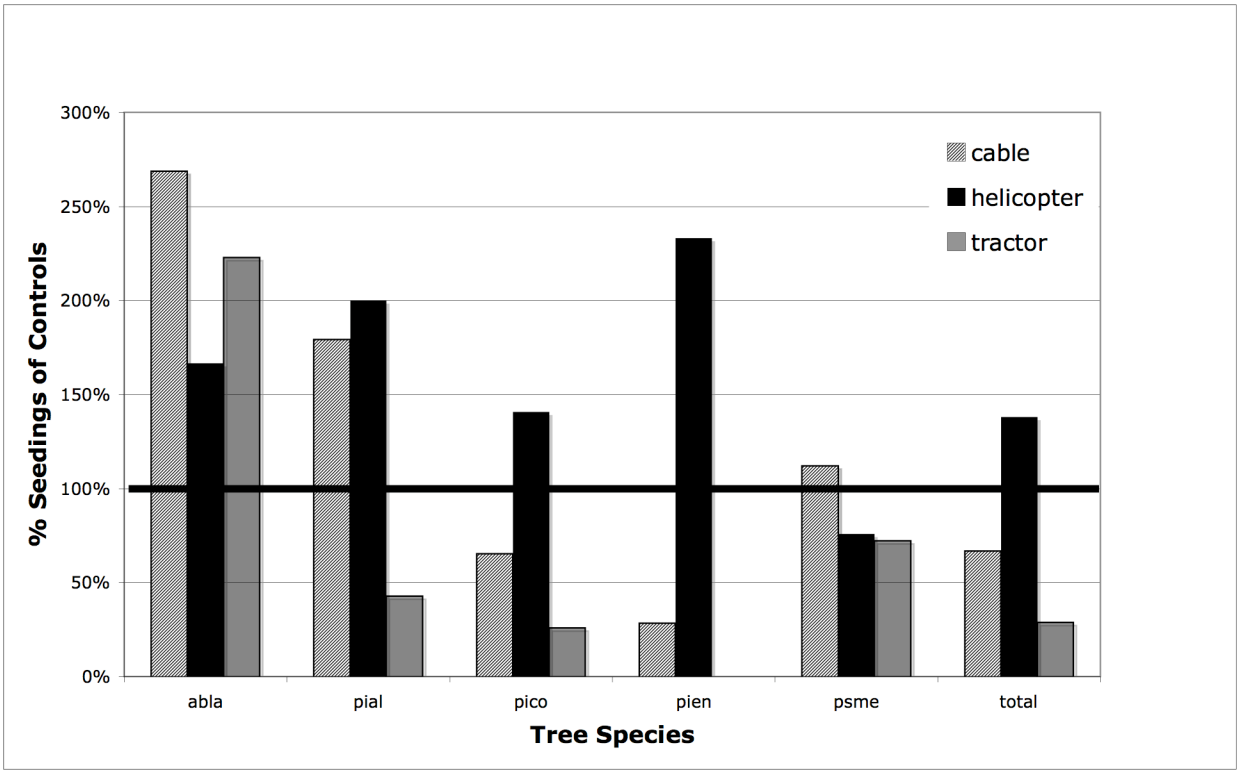


Figure 9. Effects of salvage logging on tree regeneration 7-10 years after treatment, Thompson Creek fire, Gallatin National Forest. Abla=Subalpine fir, pial=whitebark pine, pico=lodgepole pine, pien=Engelmann spruce, psme=Douglas-fir.

## VI. Conclusions and Recommendations

From our preliminary assessment of post-fire or salvage logging it appears that in terms of vegetation and forest regeneration our ecosystems are relatively resilient to this form of disturbance. Forest regeneration was adequate in all sites, and in the 2003 burn sites was often more vigorous on logged sites than the controls. Harvest and yarding techniques still show important effects. While cable and helicopter yarding had little effect on vegetation or tree regeneration, tractor logging resulted in increased disturbance including mineral soils exposure, and invasion by grasses and reduced tree regeneration for some species. It appears that vegetation response to disturbance varies according to climatic setting and ecological context. In our 2003 burn plots there was a suggestion that dry exposed sites were more sensitive to post-fire logging than mesic sites. Our trends were consistent between the plots monitored that were logged 1-2 years prior to measurements as well as the plots that were logged 7-10 years prior to measurements. In both cases natural tree regeneration was adequate and differences in vegetation between

logged and unlogged were not significantly different except in the case of some of the tractor logged plots.

As other authors have noted the vegetation response to post-fire logging, and logging in general is extremely variable (e.g. McIver and Starr 2000). Site factors such as soils, and pre-fire stand conditions, fire behavior, and the manner in which logging was done can all influence the results. Even with 6 replicates as in the case of the Thompson Creek fire, there was substantial variability in vegetation response between plots limiting our ability to detect treatment effects. Because of this variability we recommend that monitoring be expanded in the region to identify the habitat types, soils and climatic conditions most likely to create problems for post-logging recovery.

There is a critical need to examine post-fire logging in low elevation forests where there is the greatest concern for noxious species invasions. Our high elevation sites were fairly resistant to weed invasions but our only warm dry middle elevation site, at Black Mountain, suggests much more substantial effects of logging are possible on these kinds of sites.

Post-fire logging can substantially reduce snag densities and associated habitats for wildlife populations. In our study areas this kind of management treatment is generally implemented on relatively small proportions of wildfire areas (<10%). Our data suggests that this level of activity is unlikely to create significant problems for revegetation or reforestation over burn areas. It is unknown what effect these treatments might have if they occurred over a larger proportion of burned units. Managers need to develop more precise guidelines at the landscape level, and maintain monitoring programs to make sure that this form of activity does not compromise resource management goals for burn units in general.

For the relatively high elevation (upper Douglas-fir series through subalpine fir series) sites it appears that conventional cable logging operations should not significantly interfere with tree regeneration and revegetation, and also do not appear to significantly increase risk of exotic species invasions. Our results are consistent with what has been in reported in the literature for other conifer forests on similar topographic settings (e.g. McIver and Starr 2000).

We recommend continued monitoring of these plots, on a 5-10 year interval to determine the broader implications of these treatments on stand development and diversity. Adaptive management strategies such as was done for the Thompson Creek plots on the Gallatin should be replicated more widely across this region to provide a stronger empirical foundation for monitoring the effects of these logging practices. In addition to all the detailed monitoring that was done on those sites we recommend documenting actual harvest removals immediately after logging activities to better determine how this influences reforestation and revegetation. Simple surveys of stumps as we did here on the 2003 burn plots may be a useful addition to the monitoring protocol since soils disturbance associated with log yarding appears to be a key factor influencing ecological responses.

It will also be necessary for monitoring studies to account for impacts associated with road maintenance or construction activities and specific habitats for key wildlife species as has been discussed in the reports of companion studies for this project by Hutto (2006) and Foresman (2006).

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